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Soil Compaction by Valmet Forwarder Operation at Soil Surface with and without Slash

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Abstract

Soil compaction by machine used in forest harvesting operation caused negative impacts for regeneration and tree growth. This research was intended to analyze the effectiveness of using slash to decrease soil compaction, to analyze soil compaction at various soil depths, and to measure rut depth at soil surface. Valmet 860.1 forwarder was used in this research. Soil compaction was measured through its bulk density, cone index, and rut depth, under the condition with and without slash. The slash comprised of twigs, branches, and leaves as wastes from harvested Acacia mangium that were stacked to a width of about 1 meter in thickness following forwarder traffic. Results indicated that slash was effective in decreasing soil compaction. About 50% increased in soil compaction by a Valmet forwarder could be reduced by using slash coverings at soil surface. The maximum soil bulk density occurred after 5 forwarder passes. Soil compaction also occurred at subsurface soil. After forwarder traffic, increasing cone index was observed at subsurface of various soil depths. Slash was effective in decreasing soil compaction up to 20 cm in soil depth, although soil compaction by forwarder operation was slightly increased until 50 cm of soil depth. Rut was not observed under the slash however rut of about 24 cm in depth was formed at soil surface without slash. Using slash as coverings for forwarder operation reduced soil damaged.

Keywords: soil compaction, forwarder Valmet, Acacia mangium, rutted, slash

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Introduction

The needs for industrial roundwood by wood processing industries in Indonesia are still greater than log productions from natural forests. Wood requirements based on installed capacity in 2000 were about 74–80 million m^3 annually. While the supplies of logs in natural forests was only 6.5 million m3 per year in addition to supply of logs from timber utilization permits and forest plantations which amounted to approximately 10 and 20 million m^3. Therefore there is still a shortage of raw material supply for timber industry by 24–40 million m^3 annually (Matangaran *et al*. 2000). The need for wood is increasing while on the other hand there is considerable wastage of timber. Use of timber in Indonesia is still less efficient, where the amount of wood used in general, is still low compared to the volume of harvested timbers. Tree parts such as stumps, branches, twigs, and defected stems are generally abandoned and become wastes. Harvesting wastes are tree parts that should be used but, due to their uneconomic value have been abandoned in the woods. Harvesting wastes in the forms of tree or left behind tree materials that have not been used in the logging area, are derived from logged trees and other damaged trees caused by felling and skidding activities. In sustainable forest management practices, such wastes should be reduced as much as possible. Branches, twigs and leaves should be used, at least as soil coverings that are passed by timber harvesting machinery. Such use of slash is very plausible to be implemented in industrial plantation forest.

Industrial plantation forest (HTI) in Indonesia was developed in 1983 and since then, several companies have been successfully planted a total area of approximately 2.3 million ha (Iskandar *et al*. 2003). Currently, these plantations have entered their annual harvesting period. Very often, harvesting of HTI areas are carried out using mechanical means. Timber harvesting machines such as forwarder, harvester and fellerbuncher are options chosen to remove timbers from the logging sites to log landing areas at forest edges to be further transported by trucks to the logyard.

The use of heavy machineries in logging areas has unwittingly caused damages to the forest soil. The negative impacts of such machines include the loss of topsoil, soil erosion and soil compaction. Environmentally friendly harvesting is thus necessary to reduce the damage of soil erosion in tropical forests (Suwarna *et al*. 2009). In addition, forest soil compaction causes reduction of forest water infiltration, increases run off, and causes difficulty for root penetration.

Researches on soil compaction due to forest harvesting operations have received much attention. Uses of forest harvesting machineries have led to increased soil bulk density, decreased soil porosity, reduced water infiltration and inhibits roots' growth (Herbaut *et al*.1996; Matangaran 2004; Matangaran *et al*. 2006). Qualities of growth sites or soil on plantation forests influence the growth of *Acacia mangium* (Wasis 2006). The effects of air pressure in tires on the formation of rut and soil compaction have been studied by Eliasson (2005) and Aruga *et al*. (2001). The high wind pressure on the tires of the forwarder has resulted in high soil compaction leading to deeper soil depth. High soil compaction occurs after several passes of the forwarder on the same passage (Sakai *et al*. 2008). Compact soil decreases water absorption, reduces air cavity around the roots and inhibits roots' growth which will reduce the rate of growth of forest plants (Nussbaum *et al*. 1995). Seedling height and length of *Shorea selanica* root are reduced due to increased soil density (Matangaran & Kobayashi 1999).

Researches on the effect of forest harvesting machinaries on soil compaction have been carried out in sub-tropical countries. Studies of slash reinforcement for Timberjack forwarder passage show that slash coverings reduce the density of the soil compared to bare soil (Marsili *et al*.1998; Diazjunior 2003). This study is different from previous researches because it is carried out in Industrial Plantation Forest of tropical region in South Sumatera under different soil conditions and equipment specifications that is the use of Valmet forwarder.

The objectives of this study are to (1) analyze the effectiveness of slash as soil covers on the passages passed by Valmet 860.1, on the percentage change of soil compaction to that of bare soil, (2) analyze soil compaction at a soil depth, and (3) measure the rut depth formed on the forwarder passage.

Method

The research was conducted in one industrial plantation forest (HPHTI) areas of South Sumatera, which supplied raw materials for pulp. The HTI covered an area of 296,400 ha and is located on Forest Group Benakat of Banyuasin District.

Based on the company data, the company's working area is located at an altitude of 10–400 m asl. The area was dominated by broad sloping area with a total of 232,841 ha (78.55%), flat areas (slope 0–8%) covering 53,264 ha (17.97%) and slightly steep area (slope of 15–25%) covering a total of 10,295 ha (3.84%).

Plant species grown on-site comprised of fast-growing species, namely *Acacia mangium* (95%) for the purpose of industrial raw material for pulps. In addition, other fast growing species were also planted, namely *A. crassicarpa, A. auriculiformis*, *Eucalyptus pellita,* and *E.brassiana*.

Wood production comprised of a whole range of logging, trimming, bucking, stacking, skidding/collection of sorting in log landings and timber transportation, performed by partners or self-management. Logging is done using a small chainsaw with a trained operator. Logging team consisted of 4 people comprised of a chainsaw operator assisted by 3 helpers. Felling, cutting and stacking were done on logging site, followed by trimming. Trimming activity was performed to remove leaves, twigs, and branches to clean the logs. Leaves, twigs and branches from the trimming activity might be collected as slash that were placed along the forwarder passage. Bucking to sorting was done by cutting the stem at exactly the length of 2.5 m starting from the base of the stem to the tip, with flat cuts. The tip parts could be cut with a minimum length of 1.6–2.0 m, while the very end of the tip with a diameter of < 8 cm were collected as slash and could be stacked on the skidding passage. Stacking is an activity to stack logged woods. Woods having more than 8 cm in diameter with a minimum length of 1.6–2.0 m were stacked to a number of 10–12 trunks to optimize timber loading to be skid to log landings. Along with stacking activities, slash layers of 4 m in width were created, where all pieces of branches, twigs, and leaves were placed. Inspection path for block officer was created by establishing a 1.5 m block in width and free from all slash and wood. Skidding was carried out after the stacking process, by using a forwarder. The harvesting activities undertaken by the company used Timberjack and Valmet forwarders, with different types of loading capacity, where Valmet forwarder was relatively new and had more loading capacity than Timberjack. As for the contracted skidding activity, corporate partners used John Deere 1710D forwarder, harvester (Cat 320D with additional head harvester) and land Ponton Excavator. Further, timber loading activities were carried out using an excavator grapple which loaded the woods from the wood stack in log landings into the logging truck for further transport to a pulp mill in Tanjung Enim.

The study was conducted at the planting area of mangium (*Acacia mangium*) of age eight years and was harvested using chainsaw to cut the log and forwarder to skid the logs to the log landings. Forwarder used for this study was Valmet 860.1. This type of forwarder had the engine of Valmet 620DWRE 6 cylinder turbo diesel with 190 horsepower and without any load weighing 15.9 tons and with a maximum load of 14 tons (Partek 2011).

Slash was placed on passages to be passed by the forwarder. Such slash included the tip of the clear bole after the mangium was logged, which consisted of leaves, branches and twigs and pieces of wood tip with diameter of less than 5 cm. Slash coverings were slash of 1 m in height, stacked along the forwarder's passages. The forwarder moved along the passage while loading pieces of mangium wood. Timber extraction was performed from both sides of the forwarder.

Soil compaction measurements were made on soils that had been passed by the Valmet 860.1 with varying number of passes, on passages with and without slash. Measurements of bulk density were done on the trails of the forwarder on soil surface using a cylindrical tube with a diameter of 5 cm and height of 5 cm. Measurements were taken at intervals of 10 m along the forwarder's passage, each repeated as much as 10 times. To identify the increase changes in soil compaction at a certain depth, measurement was taken using cone penetrometer. Cone penetrometer was pushed from the ground up to 50 cm into the soil. The cone index value was recorded as the value of soil compaction at each additional 10 cm in depth. In addition to measurements of soil compaction, measurements of rut due to the forwarder's trails were also measured. Measurement using cone penetrometer and measurement of rut followed the position of the location of

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bulk density measurements with ten times repetitions at intervals of 10 meters along the forwarder's track. As a control value, bulk density and cone index prior to forwarder's pass (undisturbed) were measured. Measurements of soil compaction (bulk density and cone index) was calculated before and after the passings of the forwarder, that is, undisturbed as controls (0 time), and 1, 2, 3, 4, 5, 8, and 10 times after passing. Locations of measurements were made on the same side of each forwarder pass. Measurements of soil density and rut were shown on Figure 1 and Figure 2.

Soil density measurement was carried out using a cylindrical tube and calculation of bulk density value (g cm^{-3}) was done using the following formula (Craig 2004). Soil mass density and bulk density were calculated based on the following equation:

$$\gamma_s = (W_2 - W_1)/V \qquad [1]$$

where:

γ_s = wet soil mass density (g cm^{-3})
W_2 = weight of wet soil and cylindrical tube (g)
W_1 = weight of cylindrical tube (g)
V = volume of wet soil sample (cm^3)

$$\gamma_d = 100\gamma_s / (100 + W) \qquad [2]$$

where:

γ_d = bulk density (g cm^{-3})
γ_s = wet soil mass density (g cm^{-3})
W = moisture content of soil sample (%)

Cone penetrometer was pushed into the soil from the soil surface to a depth of 50 cm. Readings of received soil resistance on the cone surface were usually taken at each interval depth of 10 cm, where the value was inputted on the formula for calculating the value of cone index or penetration resistance as follows (Tada 1987):

$$T_p = (0.384F_p + W) / A_k \qquad [3]$$

where:

T_p = penetration resistance/cone index (kgf cm^{-2})
Fp = measured penetration force on the penetrometer (kgf)
W = weight of equipment (kg)
A_k = cone base area 3.23 cm^2

Results and Discussion

Soil type at the study site is a red-yellow podzolic (ultisol) with soil texture composition of 13.24% sand, 32.63% dust, and 54.13% clay. The average soil moisture content of the study site was 23%. The slash used originated from mangium wastes which were harvested 3 days prior to the operation of the forwarder. The field topography was relatively flat with slopes between 0–8%. Results of measurements of soil compaction on soil with and without slash coverings, were indicated by the bulk density value shown on Table 1.

Results of the research showed an average soil compaction of 0.9 g cm^{-3} prior to forwarder's passing on undisturbed conditions. Soil compaction would increase with increasing number of passes. The more the number of passes, the higher the soil compaction, both on soil with or without slash cover

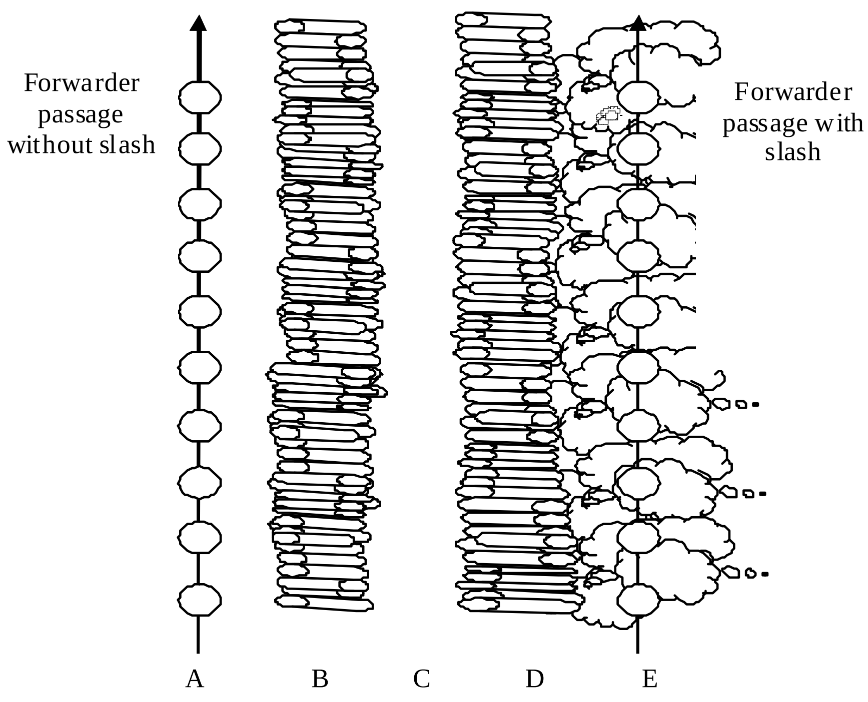

Figure 1 Pattern of Valmet 860.1 forwarder passage with and without slash coverings. A and E are forwarder tracks, B and D are wood piles, C is inspection lane, sign O is the location of the measurement of bulk density/cylindrical tube, cone penetrometer, and rutted soil.

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Rutted (cm)= (L+R)/2

Figure 2 Illustration of measurement of rutted. L: depth of rut due to left wheel (cm), R: depth of rut due to right wheel (cm).

Table 1 Average density of soil bulk density and changes in soil density on passages without and with slash coverings

Total number of passes	Bulk density without slash (average ± st. dev) (g cm^{-3})	Percentage of density increase without slash (%)	Bulk density with slash (average ± st. dev) (g cm^{-3})	Percentage of density increase with slash (%)
0	0.90 ± 0.09		0.90 ± 0.08	
1	1.19 ± 0.08	32.22	0.99 ± 0.08	10.00
2	1.24 ± 0.06	4.20	1.08 ± 0.07	9.09
3	1.28 ± 0.05	3.23	1.13 ± 0.06	4.06
4	1.29 ± 0.06	0.78	1.21 ± 0.05	2.52
5	1.32 ± 0.05	0.78	1.22 ± 0.05	0.82
8	1.32 ± 0.04	0	1.23 ± 0.04	0.82
10	1.32 ± 0.04	0	1.23 ± 0.04	0
Total		41.21		27.31

ings. Percentage increase of soil compaction without slash was larger than with slash. At a condition of one pass, the percentage increase of soil compaction was 32.22% on condition without slash, while the increase of soil compaction with slash covering was only 10.00%. The maximum soil compactions occurred after 5 passes on soil without slash and 8 passes on soil with slash. The total percentage change in soil compaction under the undisturbed condition to maximum compaction was equal to 41.21% (without slash), and 27.31% with slash. The use of slash coverings could reduce soil compaction by nearly half.

Changes in increased soil compaction occurred only up to 5 passes on soil without slash and with slash coverings. Between 5–8 passes, there were no changes in soil compaction level (Figure 3). Research by Eliasson (2005) shows an increase of soil compaction reaches 17%, because the forwarder used in such research had less loads compared to the forwarder used in this study. Study by Sakai *et al*. (2008) show that slash was effective in reducing soil compaction. Therefore, based on the results of this study, use of slash to reduce soil damage by compacting the soil on logging areas could be considered.

Change in soil compaction due to forwarder passes on soil without slash and with slash coverings tent to show similar pattern. Sharper slope occurred on soil without slash, which showed that drastic difference in soil compaction increased occurred on soil without slash on one pass compared with soils without slash coverings. Subsequently there was a slight increase up to the number of 5 passes. After the fifth pass, soil compaction of soil without slash coverings was relatively constant although soil compaction on soil without slash coverings was higher than soil with slash coverings. Soil compaction with slash coverings reached its maximum value after 8 passes followed by relatively constant soil compaction.

Previous study (Matangaran 1999) shows increased soil compaction occurred at the beginning of the bulldozer passage and reached its maximum compaction level after the sixth passes and subsequently constant. This was caused by different types of machines and types of bulldozer passage that was differed with forwarder tires. Other study suggests similar results where changes of increased soil compaction with and without slash coverings tent to form a similar pattern (Sakai *et al*. 2008). Increased soil compaction which tent to be higher at the beginning of the passage occurred since the percentage of decreased soil porosity occurred more frequently at the beginning of the soil compaction process (Nugenta *et al*. 2003; Lotfian & Parsakhoo 2009), however the maximum soil compaction occurred on the number of different passages depending on the type of harvesting machines. Research in Buenos Aires by Botta *et al*. (2009) show an increase in soil compaction after 5 times passages of the tractor. Lotfian's and Parshakhoo's (2009) research in Iran indicate that skidder reach a maximum value of soil compaction after 18 passes.

Results of this study suggested that the total number of

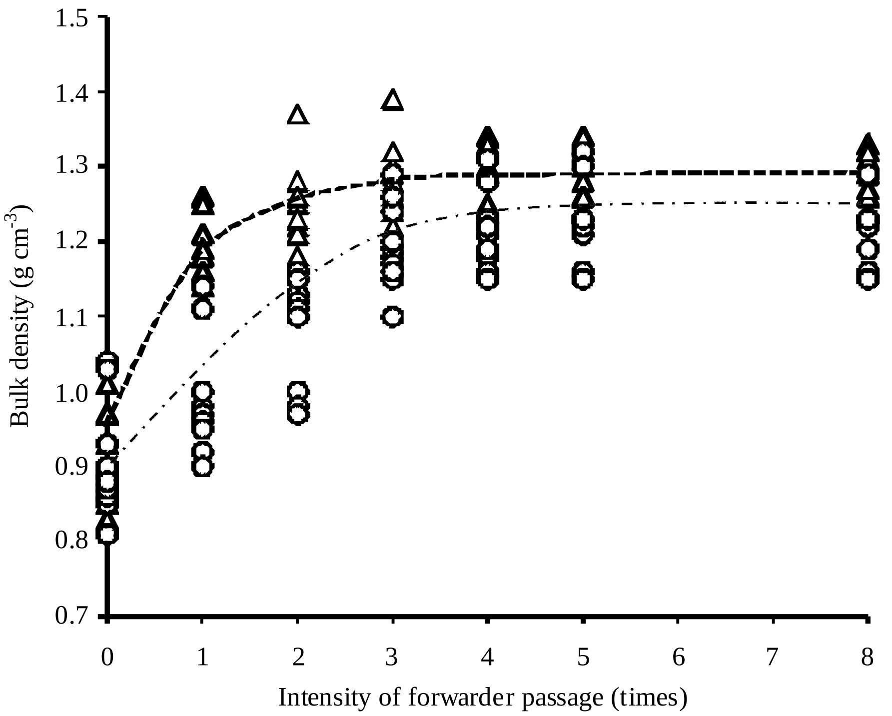

Figure 3 Tendency of increased soil density of soil with and without slash on the intensity of Valmet 860.1 forwarder passage. △without slash, ○with slash, - - - - mean bulk density without slash, - . - . - mean bulk density with slash.

four or five passes could be considered if restrictions on the number of forwarder passages were to be implemented to reduce soil damage. Akay *et al*. (2007) has develop a transportation model by entering number of passages and spacing of skid trails.

Figure 4 and Figure 5 showed the soil compaction values at soil surface measured using a cone penetrometer as indicated by the cone index on axis. The larger the cone index value, the more compact was the soil. The ordinate showed soil depth from soil surface (0 cm) to a depth of 50 cm.

Soil compaction that formed under the conditions of no forwarder passes was shown from the cone index value at 0 times passes (undisturbed). Soil compaction on soil surface which have not been passed by forwarded indicated that the deeper the soil the more compact it was. The average cone index value of soil without forwarder pass, both on soil without and with slash obtained the similar value, which was equal to 4.49 kgf cm^{-2}. Forwarder pass increased the cone index value of the soil surface to 2 times greater than undisturbed conditions.

The compaction of soil surface without slash which was indicated by the cone index value related to the number of forwarder's pass (1–10 passes) resulted in a range of values of about 8.5–10 kgf cm^{-2}, while under the condition of soil with slash coverings showed a cone index value between 5.7–9 kgf cm^{-2}. This suggested that the use of slash for coverings was in reducing soil surface compaction due to the movement of the forwarder.

Soil compaction with and without slash coverings at depths of 10 and 20 cm indicated that the value of cone index increased with increasing intensity of the passage of the forwarder. At a depth of 10–20 cm the cone index values were smaller on soil with slash coverings. On the condition of 1–3 forwarder passes, the cone index value showed a smaller value on the condition of soil with slash coverings than without slash. On the next number of passes (4–10 passes) the cone index values tent to cluster and larger even although the value of cone index for soil with slash covering was still smaller than the value of soil without slash. At soil depth of 30–50 cm, there was some slight increase of cone index values compared to depths of 10–30 cm. Changes in increased soil compaction occurred from surface soil to a depth of 50 cm, although the greatest increased occurred from surface soil to a depth of 30 cm.

Study by Sakai *et al*. (2008) showed that increased of soil compaction following increased cone index occurred only to a depth of 21 cm while at depths deeper than 35 cm there were no significant changes. Based on previous research results, if planting was to be conducted on ex-logging area, it is necessary to perform land preparation for planting which required a minimum depth of 35–50 cm.

Weight of forwarder plus loads had caused pressure on the wheel surface area of the contact with the ground. Pressure per unit area was known as ground pressure. High ground pressure occurred when surface of the tires received loads that were considerably high while the contact area was rela-

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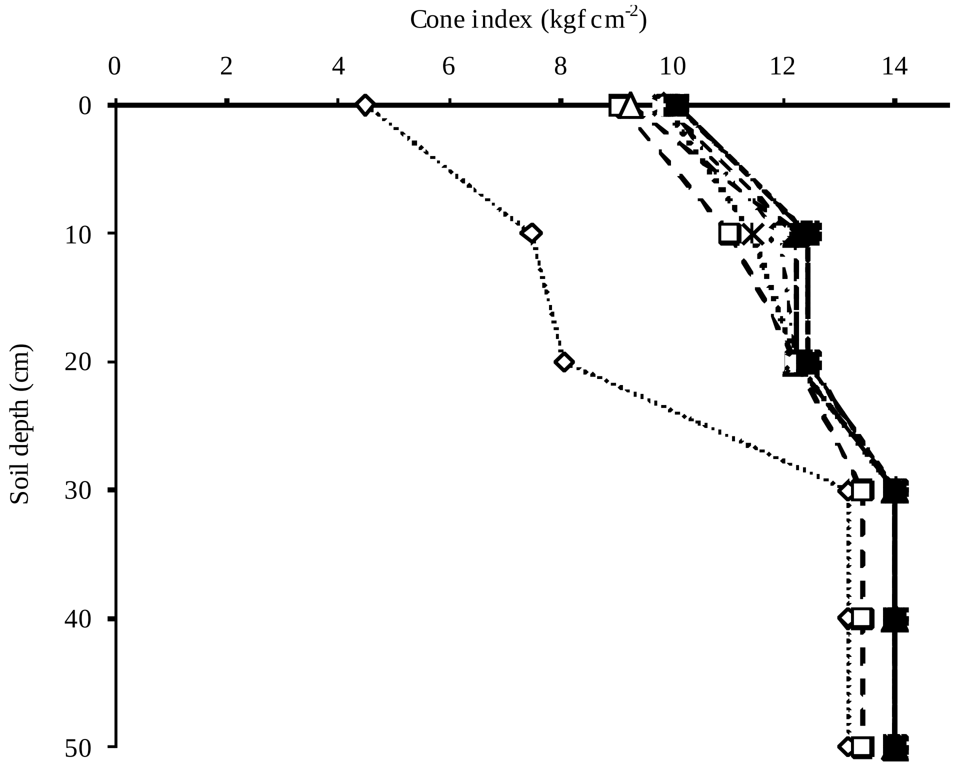

Figure 4 Density of soil (cone index) up to 50 cm in soil depth on bare soil condition (without slash). ◇ undisturbed, □ first time passage, △ 2 times passage, * 3 times passage, X 4 times passage, O 5 times passage, + 8 times passage, ■ 10 times passage.

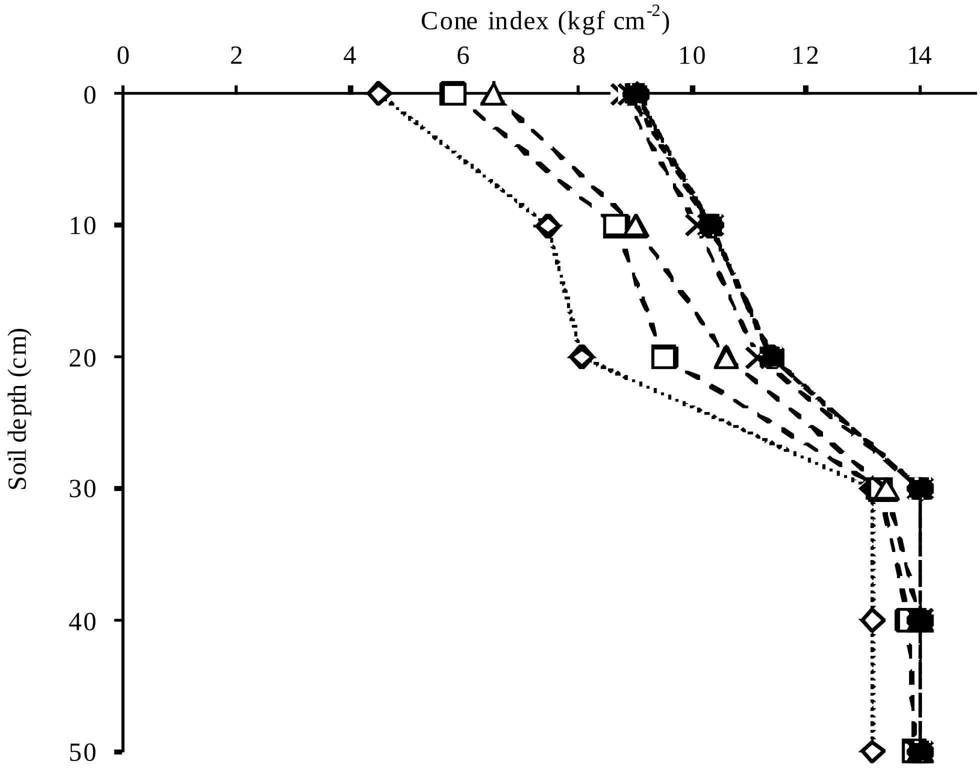

Figure 5 Density of soil (cone index) up to 50 cm in soil depth on surface soil covered with slash. ◇undisturbed, □ first time passage, △2 times passage,*3 times passage, X4 times passage, O 5 times passage, + 8 times passage, ■10 times passage.

Table 2 Rutted soil due to passage of Valmet 860.1 forwarder on soil without and with slash

Total number of passages	Rutted soil without slash (cm)	Rutted soil with slash (cm)
0	-	Rutted soil was not observed at all passages
1	15±3.5	
2	19±2.3	
3	21±2.0	
4	23±1.6	
5	24±1.2	
8	24±1.1	
10	24±1.1	

tively small. Ground pressure often caused the formation of rut on soil surface.

Ruts were formed on several places on soil surface, particularly near log landings. There were more ruts forms on soil near log landings both in number and depth compared to those located away from the landings. This was caused by the high intensity of forwarder pass.

The area of rutted soil without slash ranged from 15–24 cm (Table 2). Such rut occurred when Valmet 860.1 forwarder was loading a 14 m^3 of wood, with averaged soil moisture content of 23%. Ruts were not formed on soil with slash coverings. This indicated that slash could effectively avoid rut formation on soil. Slash is coverings that distributed the load bearing tires toward the thickness and sides of slash.

A study in Iran showed that rut formation reaches 3.29 cm (Lotfalian & Parshakhoo 2009), whereas study by Sakai *et al*. (2008) obtain a figure of 17.5 cm for rut depth. Research by Nugenta *et al*. (2003) obtains an average rut depth of 21.5 cm on soil water content of 14.9%. The result of this study showed that the average value of maximum rut was really deep that is 24 cm. This was caused by the high percentage of soil moisture content (23%), which resulted in soft soil condition thus easily formed into ruts. A research by Akay *et al.* (2007) used rut boundaries and cost of skidding to regulate spacings of skid trails and size of forwarder that might be allowed to reduce soil damage.

To reduce soil damage due to rut formation, considerations on the allowable soil water content to perform forwarding activities (skidding using forwarder) was necessary. Calculation of dry and rainy days could be considered to determine forwarding activities.

Conclusion

Slash was effective in decreasing damages to forest soils such as soil compaction on logging sites. The use of slash coverings could reduce the level of soil compaction by nearly 50%. The more the number of passes, the higher was the soil compaction with and without slash. With slash covering, the rate of increase of soil compaction was lower than that of soil without slash with an increase number of passes. Increased soil compaction occurred from the soil surface up to a depth of 30 cm, and continued to show constant decline until a depth of 50 cm. The use of slash coverings with lower cone index values showed a reduction in soil compaction to a depth of 20 cm as compared to soil without slash. The maximum average value of rut formation without slash was as deep as 24 cm, while slash coverings did not formed ruts. This indicated that slash was effective in decreasing soil damage.

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